Heavy Quarks as a Probe of a New State of Matter

I. Evidence for a New State of Matter

The atomic nuclei of all elements are bound together by the strong nuclear force. The modern theory of nuclear matter and the strong interaction is *Quantum Chromo-Dynamics* (QCD). According to QCD, the basic building blocks of matter are a relatively small number of *quark* species, which are held together by the exchange of *gluons*. Despite the impressive successes of QCD in explaining numerous features of nuclear interactions, the existence of quarks and gluons can only be inferred from the experimental data, since these basic constituents are confined by the strong force. As a result, bare quarks cannot be separated by distances larger than 10^{-13} cm (or 1 fermi) from one another. Conversely, at short distances or asymptotically large energies, the force binding quarks and gluons becomes weaker. It is for the discovery of this property of *asymptotic freedom* of QCD that the 2004 Nobel Prize in Physics was awarded.

QCD and asymptotic freedom predict that nuclear matter undergoes a phase transition at sufficiently high energy densities and temperatures, dissolving into a plasma of its constituent quarks and gluons. Discovering the *quark-gluon plasma* (QGP) and measuring its properties will further validate QCD as the theory of nuclear matter.

The QGP phase transition is predicted to occur at a critical temperature $T_c \sim 170$ MeV = 2×10^{12} ^oK, some 130,000 times higher than the temperature at the core of the sun. Such enormous temperatures are believed to have existed a few microseconds after the Big Bang. The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) provides the unique opportunity to recreate these conditions of the early Universe today. At RHIC, gold (Au) nuclei are accelerated to velocities close to the speed of light and collided (nearly) head on. For a fleeting moment of 10^{-22} sec after each of these Little Bangs, a fireball of nuclear matter is created, with energy densities high enough to produce the QGP phase predicted by QCD. During this short time scale, the only diagnostic probes available are internally produced particles.

Comprehensive analysis of the copious experimental data collected at RHIC provides two very strong indications [1,2], never seen before in lower energy experiments, that a new state of matter is indeed being created in relativistic heavy ion collisions:

a. Angular asymmetry of particle production: Collisions between two nuclei which are not exactly head on produce an overlap region with an elliptic shape. Pressure gradients, due to the thermalized strongly interacting matter, are larger along the short side of the ellipse, producing a more energetic expansion and more particles in that direction [1]. This angular asymmetry in the resulting distribution of particles can be characterized by its second moment, called the elliptic flow coefficient v_2. Figure 1 shows that v_2 as a function of particle transverse momentum p_T is consistent with a hydrodynamic model of the expansion based on the QCD equation of state (EOS) which includes the QGP phase transition.

b. Suppression of energetic particles: When quarks and gluons undergo hard scattering they produce showers of energetic particles called *jets*. If a jet is produced in a region of high ambient energy density, it should be strongly absorbed or *quenched* during its propagation through the opaque plasma relative to ordinary nuclear matter [2]. This jet quenching phenomenon was predicted as a signature for the creation of the QGP [3]. Figure 2 shows strong particle attenuation in head-on Au+Au collisions (black squares), in agreement with theoretical expectations for the QGP.

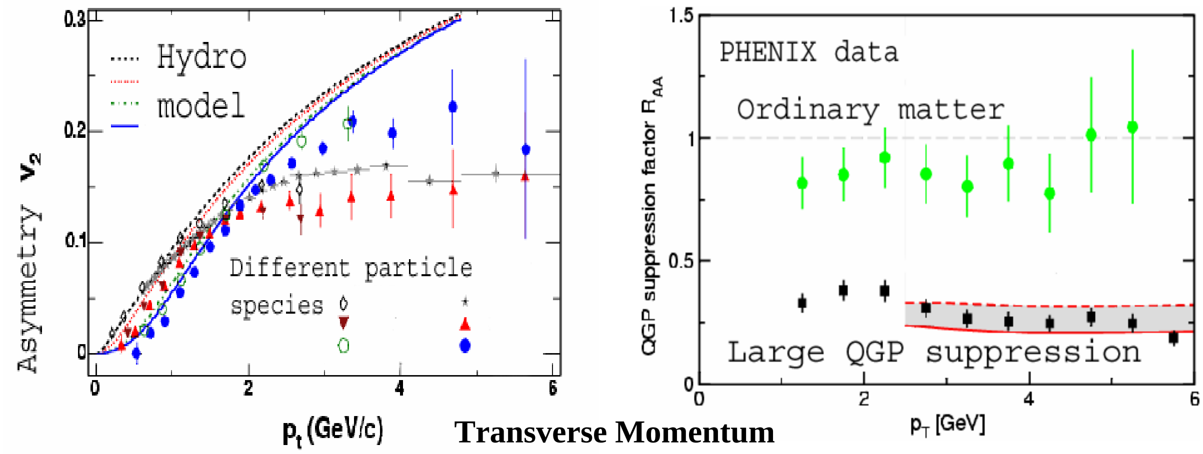

Figure 1. Azimuthal asymmetry v_2 as a function of transverse momentum p_T [1]. The low p_T (< 2 GeV/c) particle distribution is in good agreement with hydrodynamic models incorporating QGP and thermalization. At high p_T particles do not reach thermal equilibrium and the hydro model fails, as expected.

Figure 2. QGP suppression factor versus p_T. Particles traveling through the opaque plasma (squares) are strongly suppressed, while little suppression is seen in cold nuclear matter (dots) [2]. Energy loss theory that includes QGP effects reproduces the observed suppression [3].

II. Heavy Quarks: The Next Frontier of Heavy Ion Physics

While evidence is mounting from measurements of particles composed of the lighter quarks (with masses less than a few hundred MeV) that a new state of matter has been created at RHIC, very little is known about its properties. Heavy quarks (called *charm (c)* and *beauty (b)*, with masses greater than 1 GeV = 1000 MeV) are widely recognized as the cleanest probes in the laboratory quest for the QGP and their analysis is the vital next step to clinch its discovery [4]. Use of such heavy particles as test charges in the plasma may be compared to the study of Brownian motion of a dust particle in a fluid - historically the first direct probe of the atomic properties of matter. Heavy quarks are not present as constituents of the colliding nuclei, but are formed at the earliest times after the collision. Once formed, heavy quarks live much longer (~10^{-11} sec) than the duration of the QGP (~10^{-22} sec), and travel macroscopic distances (up to a few mm) away from the creation point. This separation of mass scales and time scales allows sampling of the properties of the plasma in a way not possible with light quarks.

III. Science and Technology Objectives

An exciting window of opportunity to determine the properties of the new state of matter created at RHIC has now opened. The primary goal of this proposal is to make the most accurate measurement of the properties of the QGP, using heavy quarks as probes. Experiments at the RHIC facility are the highest priority of the national nuclear physics program and are specifically identified as strategic priorities in Section 7.3 of the LDRD DR white paper. We propose to construct a silicon micro-vertex detector (SVD) with state-of-the-art position resolution, speed and low power consumption to make these heavy quark measurements. Developing the proposed detector is a natural extension of our leadership role in the PHENIX experiment at RHIC. We designed and constructed the muon spectrometers that cover the forward and backward regions of the PHENIX detector and are directing the analysis of the muon data. Integrating the SVD with the forward arm of the PHENIX detector in 2008 will ensure a leadership role for LANL in the detection and analysis of heavy quark data in this flagship of the national nuclear physics program.

We propose a closely integrated theoretical effort to develop the tools necessary for the full interpretation of the new data, including state-of-the-art perturbative QCD, lattice QCD and non-equilibrium field theory calculations. We will address the current pressing questions in heavy ion physics: Are the interactions in the plasma so strong that heavy quarks are quickly equilibrated and exhibit hydrodynamic flow? Do heavy quark bound states (e.g. charm anti-charm) dissociate in the QGP at extreme pressure and temperature? What is the mechanism of energy loss for heavy quarks in the plasma?

IV. QGP Theory, Lattice Simulation and Heavy Quark Measurements

Winning the race to discover the properties of the new state of matter created at RHIC will require much more comprehensive theory, simulation and experiment than currently exist. We outline below our approach to meet the science and technology objectives of this proposal.

a. Quark-Gluon Plasma Theory: In collisions of heavy nuclei at relativistic velocities, a fireball is created in conditions far from thermodynamic equilibrium. Yet existing hydrodynamic models assume perfect thermalization from a very early time (1 fermi/c), some 5 to 7 times faster than expected by estimates based on hard scattering processes. The inference is that softer collective processes are necessary to account for the apparent success of the hydrodynamic models. Elucidating the thermalization mechanism of the QGP is a major challenge, whose solution has broad application to science-based prediction of plasmas and other forms of matter under extreme non-equilibrium conditions. In this proposal we will build upon the existing expertise in T-Division in non-equilibrium methods [5] to investigate the collective gluon properties necessary for rapid thermalization of the plasma systematically for the first time. We will employ recently developed methods of incorporating both soft and hard collisional processes to evaluate the transport coefficients (viscosity, conductivity and diffusion) and equilibration mechanism(s) of the QGP state.

The computation of transport coefficients relies upon the identification of the correct collective degrees of freedom in the plasma. The rapid thermalization time and short mean free path for the quasi-particle excitations indicate that the new state of matter at RHIC behaves more like a liquid rather than a gas of quarks and gluons. The inclusion of non-perfect fluid terms into hydrodynamic models and comparison with experimental data on elliptic flow for heavier quark species will probe the liquid-like behavior of the QGP for the first time.

The energy lost by a particle as it traverses the plasma is a fundamental probe of the plasma's properties. The dominant source of attenuation of fast quarks is gluon radiation stimulated by the medium. We have developed a fist principles QCD approach to calculate this energy loss [6]. At present, the model requires two phenomenological inputs, the mean free path λ and Debye screening mass μ_D in the plasma. Current determination of the properties of the QGP from the observed suppression of light quarks is limited to the single quantity μ_D^2 / λ. The improved theory of quasi-particle degrees of freedom in the QGP enables both the independent determination of these two important quantities and their implementation in energy loss calculations.

Charm and beauty quarks introduce larger mass scales M_c = 1.3 GeV and M_b = 4.5 GeV, which modify the quantum interference pattern of jet interactions in the plasma [7] and the amount of energy loss. This new scale dependence provides another method of obtaining λ and μ_D separately from the data. Thus, improved theoretical control of thermalization and energy loss mechanisms and their dependence on the mass of the quarks involved will make the theory of QGP much more predictive, allowing for the extraction of fundamental parameters of the plasma state from the proposed heavy quark measurements.

b. Lattice Simulations: Charm and beauty quark bound state production and propagation should be significantly modified by the plasma and could lead to a large detectable suppression relative to measured yields in proton-proton reactions (where QGP is not formed). The dissociation of these bound states, which consist of quark-antiquark pairs, is a sensitive probe of the temperature and energy density of the plasma phase. Experimentally, one measures the number of bound states and their distribution in energy. Theoretically, the properties of bound states (mass, width, decay constant) versus the temperature are given by spectral functions, which can be determined by a lattice QCD simulation [8]. To quantify the difference between zero and finite temperature behavior of these spectral functions, the calculations have to be done with a large number of lattice points. Simulations must also achieve control over lattice discretization artifacts. The lattice spacing should be sufficiently fine to simulate the detailed behavior of the heavy quark potential as a function of the distance. Existing calculations of the behavior of bound states indicate that while some states may survive up to T = 350 MeV, others dissolve around T = T_c = 170 MeV [8]. A much better understanding of the spectral function and statistical noise reduction methods is needed to obtain reliable estimates [8,9]. We propose to investigate improved lattice actions to reduce the associated systematic uncertainties, and obtain a more accurate thermometer (or EOS) for measuring the QGP temperature. This improved EOS will be compared with both the quasi-particle theory and new heavy quark data.

c. Heavy Quark Measurements: Currently, detectors at RHIC make only indirect measurements of heavy quark production. Charm and beauty particle decays often produce an electron or a muon. The experiments measure the sum of all produced electrons or muons, which include contributions from other decays. These light quark backgrounds must be subtracted to yield pure heavy quark spectra. Since the backgrounds are greater than the size of the signal, the systematic errors on the heavy quark yields are significant. The large uncertainties are exemplified by the heavy quark cross sections obtained by the PHENIX and STAR experiments, which differ from each other by as much as a factor of three or four, but are within error bars of each other.

Electron measurements have been used to estimate the flow of charm quarks. The PHENIX data, shown in Figure 3 [10], also suffer from the limitations of particle identification and the inability to separate beauty and charm components. The data are not accurate enough to prove or refute thermalization of heavy quarks in the plasma. Measurements of the production of electrons in dense matter, shown in Figure 4 [11], likewise are not precise enough to determine if heavy quarks are suppressed in hot dense matter, relative to normal nuclear matter. For comparison, see the small error bars in Figures 1 and 2.

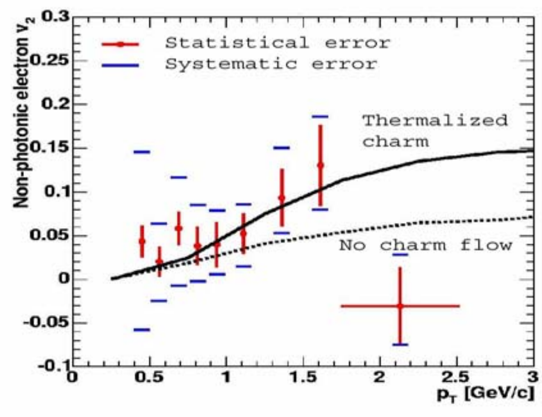

Figure 3. Azimuthal asymmetry v_2 for charm after background subtraction [10]. The solid curve is the prediction for charm quark thermalization, while the dashed curve is without thermalization. Note the large systematic errors.

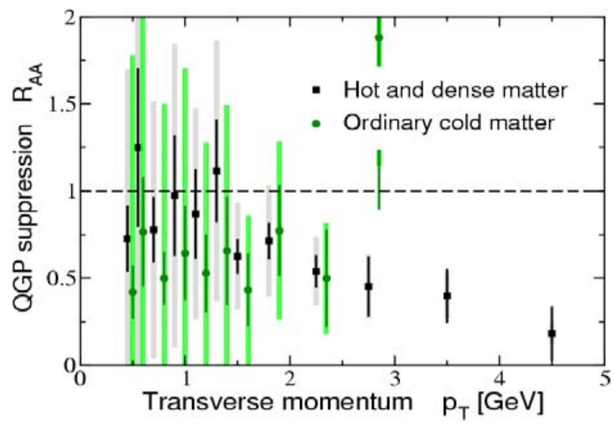

Figure 4. Suppression of charm in hot dense matter (squares) versus cold nuclear matter (circles) [11]. Within the large statistical and systematic errors, there is not adequate sensitivity to the properties of the QGP.

Given the uncertainties associated with the indirect extraction of the charm and beauty signal, current experiments at RHIC cannot fully utilize the tremendous potential of heavy quarks as accurate probes of the new state of matter. The Silicon Micro-Vertex Detector design we propose below will eliminate these large systematic errors, providing the first precise measurements of heavy quarks in heavy ion collisions, including their elliptic flow, energy loss and production cross sections.

V. Heavy Quark Detection Using a Forward Silicon Micro-Vertex Detector

a. Identification of Heavy Quarks using Distance of Closest Approach: Charm and beauty particles can be identified cleanly by measuring their lifetimes. These are ~1 picosecond, which translate into a decay distance of ~1 mm at forward angles. At present, none of the existing RHIC detectors have sufficient spatial resolution to pinpoint these decay vertices. Our strategy is to use a silicon micro-vertex detector (SVD) to precisely measure the decay distance, together with a PHENIX muon arm (Figure 5) to identify the decay muon and record its momentum. We have previously used this method to detect beauty quarks at Fermilab [12]. Only silicon detectors have sufficient position resolution and radiation hardness for this purpose.

Deploying the SVD in the forward region significantly improves the rejection of backgrounds, due the larger separation between the heavy quark production and decay points. The resulting unambiguous tagging of heavy quarks will provide a probe of the QGP with an order of magnitude reduction in systematic errors, compared with current measurements.

Figure 6 shows how the SVD is used to identify the decay of a heavy quark. The two heavy ions intersect at the indicated collision point, where a charm particle (D^+) is produced. The D^+ then travels a certain distance where it decays to a muon (μ^+). The four planes of the SVD precisely record the trajectory of the muon. Using this trajectory, the distance of closest approach (DCA) of the muon to the collision point is determined. The decay distance and hence the lifetime of the heavy quark are proportional to the DCA. Backgrounds from processes other than heavy quark decays are eliminated by rejecting events with too short or too long a lifetime. Beauty and charm can be separated from one another by taking advantage of the longer lifetime of beauty particles and the higher momentum of muons from their decays. Additionally, some beauty decays produce two muons, while charm decays do not.

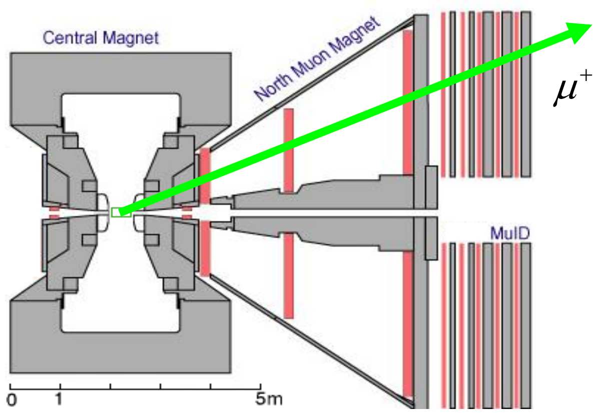

Figure 5. The north PHENIX muon detector, one of two arms designed and instrumented by our team at LANL. The SVD will be placed at the center of the central magnet (beginning of arrow). Note the different size scale between the muon arm and proposed SVD (Figure 6).

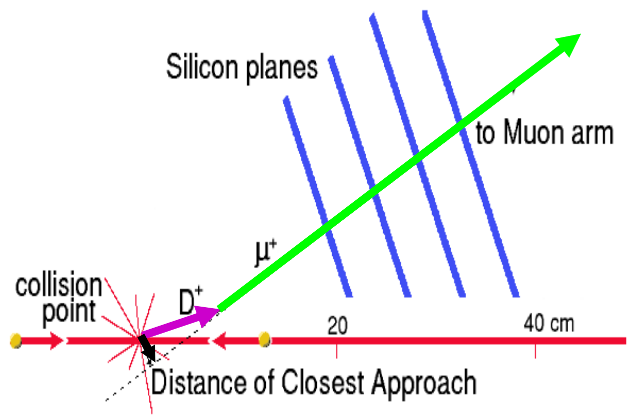

Figure 6. Identification of charm particle (D^+) using the SVD. The distance of closest approach (DCA, small black arrow) of the decay muon trajectory to the collision point is precisely measured using four silicon planes. Backgrounds from the collision point or from long-lived decays are rejected using a cut on the DCA value

b. Silicon Pixel Detector Technology: The optimal technique for detecting displaced vertices of heavy quark decays is the use of finely segmented silicon detectors. Factors such as occupancy, radiation dose, power and cost dictate that the detectors be composed of mini-strips, with strip sizes of 50 µm by a few cm. Our proposal is to build an SVD covering ¼ of one of the LANL-built PHENIX muon spectrometers (Figure 5), which will be used to measure charm and beauty decays at RHIC. This effort will also advance the state-of-the-art in silicon detectors and perform the R&D necessary for a DOE proposal to fund the construction of a much larger SVD covering both PHENIX muon arms.

Our SVD design has several unique features compared with existing devices:

- Ability to efficiently find tracks in very high multiplicity Au+Au collisions.
- Superb resolution capable of pinpointing vertices from charm decays.
- Very low mass to minimize multiple scattering and very low power consumption.

Simulation studies performed under a previous LDRD-ER grant [13] yielded the design for the SVD shown schematically in Figure 6. The four layers of silicon mini-strips consist of strips 50 µm wide in the radial direction with strip length of 2mm at the minimum radius and increasing to 13 mm at the outer radius. The strip lengths are chosen to equalize particle rates across the detector. This minimizes the channel count and significantly reduces the power consumption, which are the two most important engineering parameters of any vertex detector. Since no electronics suitable for instrumenting these mini-strips presently exists, we have formed a collaboration with experts at Fermilab to modify one of their prototype integrated circuit designs for our use.

This new and unique silicon chip and sensor design has generated significant interest around the world where people see a need for a low power, low cost, flexible chip design for new vertex detectors. Of special importance is a factor of 10 reduction in power consumption, compared with current technology, which minimizes cooling requirements and reduces the total amount of support structure. Another unique feature is the extremely high serial readout speed of 840MHz, far beyond any existing detector, coupled with direct fiber optic readout using a newly developed chip from the University of Heidelberg. Thus, we are breaking new ground both in terms of detector technology and in heavy ion physics, since no other collider experiment is looking at heavy quark decays in the forward region.

This leading edge technology brings exciting new capabilities to LANL in areas where low cost, high-resolution imaging capabilities are needed. Examples include high resolution Compton imaging in medical and biomedical applications, space instrumentation where low power is essential, and stockpile stewardship applications where high speed, higher resolution imaging is required. The readout speed of this electronics opens the door to dynamic proton radiography for more sophisticated applications.

The following cost estimates to cover ¼ of a PHENIX muon arm are based upon our previous experience with silicon detectors and were cross checked by experts at Fermilab and Heidelberg.

Silicon Sensors	Front End Chips	Wire Bonding	Flex Cables, Hybrids	Fiber Optics	Receiver	Power Supplies + Cables	Support Structure	Total + 30%
$130 K	$90 K	$75 K	$152 K	$25 K	$40 K	$30K	$60 K	$785 K

Table 1. Cost estimates for SVD hardware and assembly covering ¼ of PHENIX Muon Arm. The total includes a 30% contingency.

c. Performance Simulations for Heavy Quarks Decays: We have simulated the performance of the proposed silicon detector in order to optimize its geometry and study its capabilities. Figure 7 shows that without the SVD, background muons overwhelm the charm and beauty signals up to a p_T of 4 GeV/c. Figure 8 shows the dramatic signal/noise improvement obtained when the SVD is used to eliminate tracks that do not point back to a decay vertex. After applying a loose DCA (vertex) cut, the background is reduced by more than an order of magnitude to well below the charm signal. The beauty signal (not shown) benefits as well.

The large numbers of charm and beauty decays detected in an SVD covering ¼ of a muon arm for a typical measurement at RHIC are given in Table 2. Combined with the excellent signal to background ratio, these recorded events enable measurements of elliptic charm flow and suppression with better than 10% accuracy. This precision is in contrast to the large (~50%) uncertainties in Figures 3 and 4. Note that no beauty decays have yet been identified at RHIC.

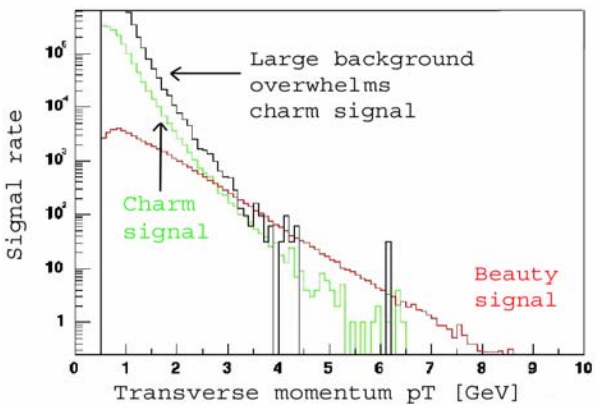

Figure 7. Simulated muon spectra without the SVD, including backgrounds from $\pi \to \mu$ and $K \to \mu$ (black line) versus signals from charm, $D \to \mu$ (green) and beauty, $B \to \mu$ (red) [13]. Note that the background is larger than the charm signal.

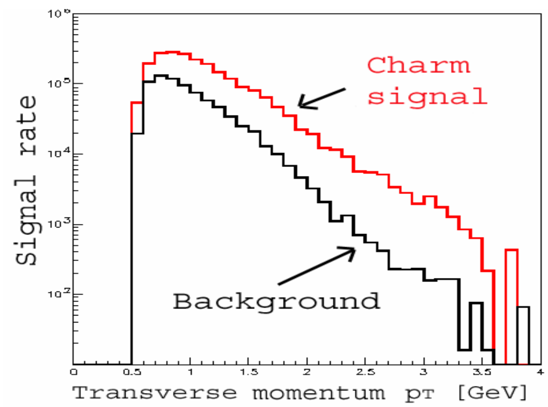

Figure 8. Result of applying a vertex cut with the SVD [13]. The charm signal now dominates over the background everywhere in the experimentally accessible transverse momentum range. Comparison to Figure 7 shows an order of magnitude improvement in the signal/noise ratio

Year & Beams	Integrated Luminosity	Charm decays $D \to \mu$ counts	Beauty decay $B \to \mu$ counts	Beauty decay $B \to \mu^+\mu^-$ counts
2007 p+p	67 pb^{-1}	56 x 10^6	48 x 10^3	480
2008 Au+Au	750 μb^{-1}	15 x 10^6	12 x 10^3	320

Table 2. Estimated number of charm and beauty particle decays collected using the SVD with PHENIX during a typical year at the RHIC facility.

VI. Summary of Project Plan and Impact of Proposed Work

Using state-of-the-art silicon technology, we will construct a vertex detector to make the world's most precise measurement of heavy quarks produced in heavy ion collisions. This will provide the vital next step in the discovery of the QGP at RHIC and elucidate its properties. We anticipate that successful completion of this R&D effort will leverage several million dollars in DOE capital equipment funding for a much larger detector covering both muon spectrometers of the PHENIX experiment. The technical expertise that we develop can be transferred to other high multiplicity collider experiments. A timely investment now will ensure an important role for LANL at the future CERN Large Hadron Collider.

The close integration of a comprehensive theoretical analysis with the experimental data and lattice simulations will provide a unique capability, placing LANL at the forefront of research on the physics of matter under extreme conditions. The theoretical tools we develop will enhance our critical expertise in predictive modeling and analysis of a highly non-linear, strongly coupled complex systems. The success of this proposal helps ensure a future for LANL at the forefront of science and technology through recruitment of first-rate postdoctoral fellows, students and retention of outstanding staff.

A. Plan for FY06:

Theory

- Determine mean field evolution of collective gluon fields with realistic initial conditions.
- Study particle production and pre-thermalization stage of the plasma.
- Investigate charm particle production and correlations in light colliding systems to establish a baseline for comparison to Au+Au.

Simulation

- Investigate improved lattice actions and different observables to reduce the systematic uncertainties in the lattice QCD calculations.

Experiment

- Complete design and produce state-of-the-art readout chip with FNAL.
- Design and procure silicon mini-strip detectors. Design SVD support structure with Hytec, Inc.
- Have industry wire-bond detectors and readout chips. Design readout bus structure.

B. Plan for FY07:

Theory

- Apply new quasi-particle resummation methods to compute an improved EOS.
- Identify quasi-particle lifetime and scattering responsible for the approach to equilibrium.
- Determine the phase space distribution of medium-induced gluon radiation for heavy quarks. Calculate the energy loss of charm and beauty quarks in the plasma.

Simulation

- Perform finite temperature lattice simulations of heavy quark bound state spectral functions.
- Determine thermodynamic observables and QCD EOS as a function of temperature with improved accuracy.

Experiment

- Assemble detector/readout, bus and fiber optic readout. Test detector/readout assemblies.
- Assemble the SVD from four layers of mini-strip detectors.
- Install the SVD in front of a PHENIX muon arm at RHIC. Connect readout to PHENIX data acquisition system.
- Test and sample data in the 2007 p+p run at RHIC to determine alignment.

C. Plan for FY08:

Theory

- Compute transport coefficients and mean free path of plasma excitations.
- Determine heavy quark mass dependence of departures from local thermodynamic equilibrium.
- Make realistic predictions for the suppression of high p_T charm and beauty mesons versus the Debye screening and mean free path in the plasma.

Simulation

- Compare predictions of Debye-screening and dissociation effects in the QGP with the measured yields of charm and beauty bound states.

Experiment

- Record production data during the 2008 Au+Au run with a fully operational SVD.
- Make world's best measurement of charm and beauty quarks, out to ~5 GeV/c, in the high multiplicity environment of heavy ion collisions.
- Establish the elliptic flow of heavy versus light quarks.
- Determine the suppression of the heavy quarks in central heavy ion collisions.

D. Budget Request: FY2006: $1250K total ($290K SVD); FY2007: $1250K ($310K SVD);
FY 2008: $1250K ($185K SVD)

- Approximately ¾ of the yearly budget is for manpower. Staff includes 3 theoreticians and 4 experimentalists, each of which will work ½ time on this project. One of the theoreticians (Vitev) is a JRO fellow, whose salary is paid by that source for the first two years. We expect 2 postdoctoral fellows and a few students will join the project once underway.
- Approximately ¼ of the yearly budget is for engineering and construction of SVD, estimated at $785K including a 30% contingency.

VII. References

Heavy Quark LDRD DR Proposal Web Page: http://p25int.lanl.gov/~plm/

[1] S. S. Adler et al. [PHENIX Collaboration], Phys. Rev. Lett. **91**, 182301 (2003).
[2] S. S. Adler et al. [PHENIX Collaboration], Phys. Rev. Lett. **91**, 072301 (2003).
[3] I. Vitev and M. Gyulassy, Phys. Rev. Lett. **89**, 252301 (2002).
[4] N. Brambilla et al., e-Print hep-ph/0412158 (2004).
[5] F. Cooper, E. Mottola and G. C.Nayak, Phys. Lett. B **555**, 181 (2003).
[6] M. Gyulassy, P. Levai and I. Vitev, Phys. Rev. Lett. **85**, 5535 (2000).
[7] M. Djordjevic and M. Gyulassy, Nucl. Phys. A **733**, 265 (2004).
[8] F. Karsch, e-Print hep-lat/0502014 (2005).
[9] P. Petreczky, e-Print hep-lat/0409139 (2004).
[10] S. S. Adler et al. [PHENIX Collaboration], e-Print: nucl-ex/0502009 (2005).
[11] T. Tabaru [PHENIX Collaboration], ICPAQGP'05 proceedings (2005).
[12] D.M. Jansen et al., Phys. Rev. Lett. **74**, 3118 (1995).
[13] P.L. McGaughey et al., LDRD ER Project # 20020043ER, completed in 2004.

VIII. Appendix – Participants and External Collaborators

Patrick L. McGaughey

Physics Division P-25, MS H846
Tel: (505) 667-1594, Email: plm@lanl.gov

Education: Ph.D., Nuclear Chemistry/Physics, University of California, Berkeley CA, 1982
Graduate Student of Glenn T. Seaborg - Nobel Prize Winner

Awards / Achievements:

- B.A. (Magna Cum Laude), Physics + Chemistry, Augsburg College 1977
- Director's Postdoctoral Appointment, LANL, 1982-1984
- Staff Member in Physics Division, 1984-present
- Floor Manager for E772 Experiment at Fermilab, 1987-1988
- Co-designer of PHENIX Experiment, 1991-94
- Project Leader for PHENIX Muon Tracking System, 1993
- Spokesman for E866 Experiment at Fermilab, 1995-1998
- Fellow of American Physical Society, 1998
- Principal Investigator for LDRD ER NPP Grant, 2001-2004
- Co-author of more than 100 publications, with 4000+ citations and 28 highly-cited papers

Primary Area of Expertise - Experimental High Energy and Nuclear Physics:

- Design, construction and operation of large experiments
- Particle detectors, electronics and data analysis

McGaughey is the Principal Investigator of this LDRD DR proposal and is responsible for detector / performance simulations. He will work 50% of his time on this project.

Emil Mottola

Theory Division T-8, MS B285
Tel: (505) 667-7646, Email: emil@lanl.gov

Education: Ph.D. 1979, Physics, Columbia University, New York
B.A. 1974, John Jay Fellow, Summa Cum Laude, ΦBK , Columbia College, NY

Experience:

- 1986 - present: Staff Member, T-8. Currently Deputy Group Leader
- 1982 - 1986: Postdoctoral Fellow, Institute for Theoretical Physics, UCSB
- 1979 - 1982: Postdoctoral Member, Institute for Advanced Study, Princeton, NJ

Recent Conferences Organized in RHIC Physics:

- “QCD and Gauge Theory Dynamics in the RHIC Era,” Institute for Theoretical Physics (ITP), UCSB, Apr. 1- Jun. 30, 2002
- “Non-equilibrium Quantum Fields," ITP, UCSB, Jan. 5-22, 1999
- “Parton Production and Transport in the Quark-Gluon Plasma,” European Center for Theoretical Studies in Nuclear Physics, Trento, Italy, Oct. 2-14, 1994
- “QCD, the Quark-Gluon Plasma and RHIC Physics,” Santa Fe Preparatory School, Santa Fe, NM, July 6-16, 1993

Relevant Selected Publications:

- “Particle Production in the Central Rapidity Region,” Phys. Rev. D **48**, 190 (1993)
- “None-quilibrium Quantum Dynamics of Disoriented Chiral Condensates,” Phys. Rev. D **51**, 2377 (1995)
- “Dissipation and Decoherence in Mean Field Theory,” Phys. Rev. Lett. **76**, 4660 (1996)

Mottola is co-PI and will lead the theoretical effort on non-equilibrium field theory. He will work 50% of his time on this project.

Melynda L. Brooks Physics Division P-25, MS H846
Tel: (505) 667-6909, Email: mbrooks@lanl.gov

Education: Ph.D., 1989 Nuclear Physics, University of New Mexico (Magna Cum Laude)
B.S., 1985 Physics, New Mexico Institute of Mining and Technology (Magna Cum Laude)

Honors / Awards:
- Tech Scholar 1984-1985, Abraham and Esther Brook award (best junior level physics student) 1984, Undergraduate Honors Work Program, 1981-1985
- G*POP Fellowship, Aug. 1986 – Aug. 1989, Durward-Young, Jr. Award (Best Ph.D. Dissertation in Physics)

DR Relevant Expertise / Accomplishments:
- Heavy Quark Physics Convener for PHENIX Collaboration (450 collaborators)
- Project leader for Muon Tracking System (collaboration of ~ 50 scientists), 1999-2002
- Software coordinator and ongoing code developer for PHENIX muon arms, 1995-2000
- In charge of test bench and subsequent testing of electronics for L3 silicon vertex detector
- Developed b-jet tagging criteria and detector requirements for SSC silicon detector
- Assembled, tested and debugged silicon microstrip detector telescope for SSC GEM and CERN L3 detectors
- Responsible for detector simulations of SSC silicon tracker
- Several years experience using, building and debugging various particle and gamma ray detectors including associated electronics.

Brooks will be responsible for data acquisition, testing and data analysis. She will spend 50% of her time on this project.

Rajan Gupta Theory Division T-8, MS B285
Tel: (505) 667-7664, Email: rajan@lanl.gov

Education: California Institute of Technology, Theoretical Physics, Ph.D., 1982

Awards / Achievements:
- 2001 – present: Group Leader for High Energy Physics, LANL
- 2000 – present: Project Manager for High Energy Physics, LANL
- 2001 – present: Principal Investigator, DOE allocation mp273 at NERSC
- 1999: Distinguished Performance Award, LANL
- 1988-2000: Principal Investigator, DOE Grand Challenges Award (ACL and NERSC)
- 1994: Elected Fellow of American Physical Society
- 1986: First simulation showing a strong first order transition in 4 flavor QCD at finite temperature
- 1985 – 1988: J. Robert Oppenheimer Fellow, LANL

Publications:
- Author or coauthor of more than 125 research papers in high energy physics, lattice QCD, statistical mechanics, computational biology, parallel computing, education, and public health.
- Co-editor of 3 proceedings

Gupta will lead the lattice QCD effort to estimate spectral functions and equation of state. He will work 50% of his time on this project.

Gerd J. Kunde Physics Division P-25, MS H846
Tel: (505) 664-0271, Email: g.j.kunde@lanl.gov

Education: April 1994 Ph.D., Physics, University Frankfurt
May 1990 Diplom, Physics, University Heidelberg
May 1986 Vordiplom, Physics, University Heidelberg

Experience:
- Dec. 2002 – present, Technical Staff Member at Los Alamos National Laboratory
- July 1997 - Dec. 2002, Assistant Professor, Physics Department, Yale University
- April 2001 - Dec. 2002, Co-convener of the High-Transverse Momentum Physics Working Group in STAR
- Sept. 1998 - Dec. 2002, Spokesman for STAR-Ring Imaging Cherenkov Detector
- Oct. 1996 - June 1997, Research Associate, National Superconducting Cyclotron Laboratory, Michigan State University
- April 1994 - Sept. 1996, *Feodor-Lynen Fellow* of the *Alexander-von-Humboldt Foundation.* Research Associate, National Superconducting Cyclotron Laboratory, MSU
- May 1990 - April 1994, Research Assistant at GSI, Darmstadt

Publications in Refereed Journals as of January 2005:
- 96 total 42 Phys.Rev.Lett., 9 Phys.Lett. B, 30 Phys.Rev. C, etc.
- ~ 3500 citations 13 famous papers (100+ citations)

Kunde will be responsible for the SVD electronics and readout. He will work 50% of his time on this project.

David M. Lee Physics Division P-25, MS H846
Tel: (505) 667-8888, Email: dlee@lanl.gov

Education: Ph.D., Nuclear Physics, University of Virginia, 1971

Awards / Achievements:
- LANL Staff Member – MP Div. 1974-1977, N Div. 1977-1982, P Div. 1982-present
- First Officer IAEA – 1980-1981
- 3 U.S. patents
- Section leader LAMPF beam line instrumentation
- Lead Physicist – LAMPF high intensity beam line
- LANL technical manager for SSC/GEM Silicon Detector proposal
- L3- CERN silicon microvertex detector
- Project leader for PHENIX muon subsystem R&D
- Subsystem manager for PHENIX muon mechanical subsystem
- Co Principal Investigator for LDRD ER NPP Grant, 2001-2004
- Co-author of more than 150 publications

Primary Area of Expertise - Experimental High Energy and Nuclear Physics:
- Design, construction and operation of large experiments
- Particle detectors, electronics and data analysis

Lee will be in charge of SVD mechanical design and integration and will work 50% of his time on this project.

Ivan Vitev Theory Division T-16 and Physics Division P-25, MS H846
Tel: (505) 667-1029, Email: ivitev@lanl.gov

Education: Ph.D., 2002 Columbia University, Theoretical Nuclear Physics
B.S., 1995 Sofia University, Theoretical Particle and Nuclear Physics

Awards / Achievements:

- J. Robert Oppenheimer Fellow, July 2004 – present
- “St.Cyrill and St.Methodius” International Foundation Fellow, 1997
- “Eureka Foundation Fellow, 1997
- Sofia University “St. Kliment Ohridski” Fellow, 1991-1995

DR Relevant Experience:

- Perturbative quantum chromodynamics (QCD)
- Energy loss theory and jet quenching phenomenology
- Jet tomography of nuclear matter under extreme temperature and energy density
- 17 publications in refereed journals in last 5 years including 4 Phys. Rev. Lett., 6 Phys. Lett. B and a book chapter
- 1400+ citations including 3 famous (100+) and 9 well-known (50+) preprints
- 48 invited lectures, colloquia, talks and seminars

Vitev will lead the perturbative QCD and heavy quark energy loss effort. He will work most of his time on this project, but his salary is paid the first two years by a JRO fellowship.

External Collaborators:

Ray Yarema's team at Fermi National Accelerator Laboratory has agreed to develop the front-end electronics for the SVD, which is presently underway.

Michel Gonin's group at Ecole Polytechnique near Paris, built much of the electronic instrumentation for the PHENIX arms. They would like to build part of the SVD electronics and develop reconstruction software.

Volker Lindenstruth's group at University of Heidelberg is developing the fiber optic interface (OASE chip), which will be used by the SVD.

G. Sterman and **G. Nayak** of SUNY Stony Brook plan to participate in some of theoretical calculations of heavy quark production.

M. Gyulassy of Columbia University has expressed interest in developing the theory of QGP, related to heavy quarks.

We expect that other members of the PHENIX collaboration would join the SVD effort, if this proposal were funded.